FLUIDIZED BED REACTOR TEST

Fluidized Bed Reactor Test Units

Two fluidized bed reactors were tested at the Adams facility. The fluidized bed reactor process consists of processing wastewater in a closed vessel containing media, such as sand or activated carbon. The fluidized bed is a biological, attached growth process where micro-organisms grow on support media. Wastewater is passed up and through the vessel at a rate to suspend or fluidize the media on which bacteria grow. In denitrification, carbon is added to the influent wastewater to carry out the metabolic processes of the bacteria. The bacteria reduce nitrate or nitrite to nitrogen gas through respiratory action, as the wastewater passes around the fluidized media. The use of small sand particles as support media provides a vast surface area for bacteria growth as compared to fixed-bed systems.

Both the FBRs used at Adams Avenue were physically identical to one another except that FBR2 was fitted with a methanol injection system. Each FBR consisted of a 22-gallon cylindrical reactor vessel, 100-gallon recycle tank, influent pump, recycle pump, associated flowmeters, and other appurtenances. The reactor vessels were clear acrylic columns, 6 feet high with an inner diameter of 9.5 inches. A schematic of the FBR is shown by Figure 25.

Fluidized Bed Reactor 1 Operations - October 12, 1993 through November 21, 1995

Testing with FBR1 commenced in October 1993. With the exception of four extended periods of downtime for maintenance to make piping and reactor modifications and to solve operational problems, the reactor was operated continuously until November 21, 1995, when operations ceased. For the entire period, FBR1 was the second stage of process Train 1 and treated the effluent of from UASBR.

The independent operation variables tested during the course of operations were feed flow rate and depth of media. The initial feed flow rate through the reactor was targeted at 1.0 gpm, with a upflow rate (influent + recycle) of 14 gpm. The target feed flow rate remained at 1.0 gpm until it was lowered to 0.5 gpm on January 20, 1995 (Day 858). The feed flow rate was lowered once more to 0.25 gpm on August 19, 1995 (Day 1069) and remained at that rate until plant shutdown on November 21. The upflow rate was adjusted to maintain 50 percent bed expansion and ranged between 8 gpm and 62 gpm. FBR1 operations were suspended for four extended periods: April 27, 1994 (Day 590) through May 9, 1994 due to problems with the UASBR; March 10, 1995 (Day 907) through March 29, 1995 due to flooding of the site; July 8, 1995 (Day 1027) through July 21, 1995 to install the HDPE cone in the UASBR; and August 29, 1995 (Day 1079) through September 5, 1995 to repair the influent line at the Lincoln pump station.

The reactor was started with media consisting of #20 sand at a settled depth of 24 inches. Media depth was changed four times during the course of operations: lowered to 12 inches on April 19, 1994 (Day 582); again lowered to 6 inches on November 3, 1994 (Day 780); raised to 12 inches on January 5, 1995 (Day 843); and again raised to 24 inches on February 10, 1995 (Day 879). Changes in media depth occurred when modifications and maintenance activities were performed on the system.

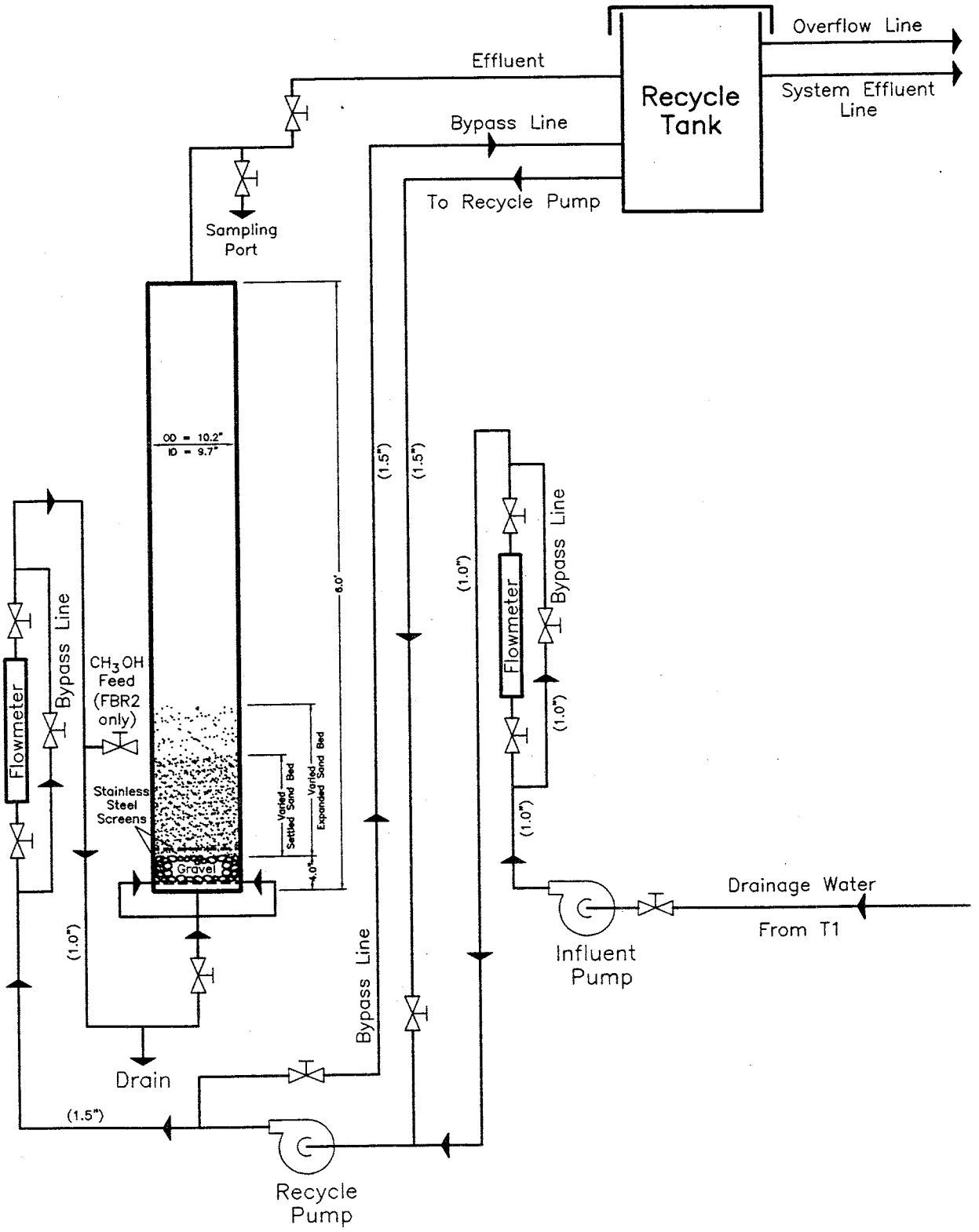


Figure 25. Fluidized Bed Reactor Schematic

(Typical for FBR1 and FBR2)

Several modifications were made to FBR1 during the test period. The influent piping from the UASBR was replumbed in the third week of August 1994 to eliminate aeration of the reactor's feedwater. The influent manifold was modified twice, the first time in April 1994 and second time in January 1995, to improve feedwater distribution into the reactor.

Operation of FBR1 was labor intensive. The feed flow rate would decrease as the particulate carryover from the UASBR accumulated in the strainer. As a result, the influent strainer was cleaned and the feed flow rate was adjusted on a daily basis. Also, the influent line between the strainer and reactor was flushed daily to remove gas and biological growth that accumulated during operations.

Other maintenance activities included cleaning of the reactor, recycle tank, and piping. Biological growth was removed from the walls of the reactor column above the fluidized bed, recycle tank, and piping. The growth in the reactor measured up to a quarter-inch thick before cleaning. The reactor and recycle tank were cleaned six and three times respectively during the 26-month testing period. Manifold modifications were primarily made because of the biological growth on the manifold and associated distribution plates and screens that caused blockage and uneven flow distribution.

Fluidized Bed Reactor 1 Results

FBR1 was the second stage of process train 1 and treated the effluent of the UASBR. FBR1's influent and effluent selenium concentrations are shown in Figures 26 and 27, respectively. Even though the FBR1's influent values are those of the UASBR's effluent, they are again shown in Figure 26 for ease of comparison with FBR1's effluent values. The influent Tse, Sse, and selenite concentrations averaged 458 ug/L, 258 ug/L, and 31 ug/L, respectively. The effluent values for Tse, Sse, and selenite were 382 ug/L, 200 ug/L and 51 ug/L.

Influent and effluent nitrate and dissolved oxygen concentrations are shown in Figures 28 and 29, respectively. Dates when the depth of media was changed (the lower, lighter shaded triangles) and when modifications were made to the influent manifold or manifold piping (the upper, darker shaded triangles) are also indicated on the top portion of both figures. From restart of the FRB1 after the project site was flooded on March 31, 1995 (Day 928) to the end of operations on November 21, 1995, effluent averaged 156 ug/L, 1.9 mg/L as N, and 0.5 mg/L for Sse, nitrate, and DO, respectively. Even though the FBR1 was wrapped with an insulation blanket, the reactor's temperature was strongly influenced by the ambient temperature. The reactor and ambient temperatures are shown in Figure 30. The average difference between these two temperatures throughout the testing period was 8.1 $^{\circ}$C. The recycle pump was the source of the heat that raised the reactor's water temperature above that of the influent. The reactor's temperature ranged between 4 $^{\circ}$C and 40 $^{\circ}$C.

Alkalinity analyses began on February 21, 1995. The change in alkalinity between the influent and the effluent was minimal. The influent and effluent alkalinity concentrations are shown in Figure 31 and averaged 335 mg/L as $CaCO_3$ and 357 mg/L as $CaCO_3$.

Influent and effluent total organic carbon total and suspended solids concentrations are shown in Figures 32 and 33. From March 31, 1995 through November 21, 1995, the influent and effluent

Figure 26
FBR1 - Influent Total Selenium,
Soluble Selenium and Selenite

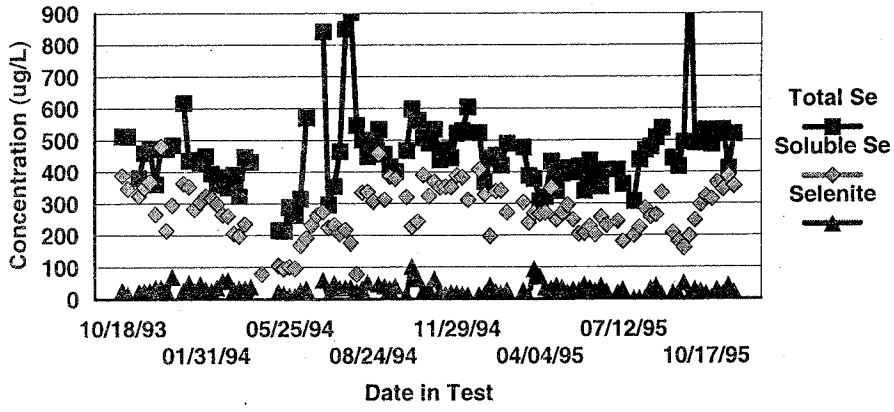


Figure 27
FBR1 - Effluent Total Selenium,
Soluble Selenium and Selenite

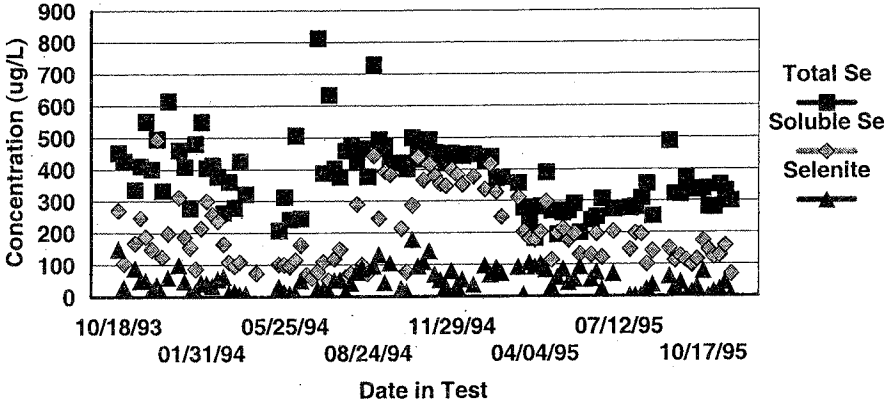


Figure 28
FBR1 - Influent and Effluent
Nitrate

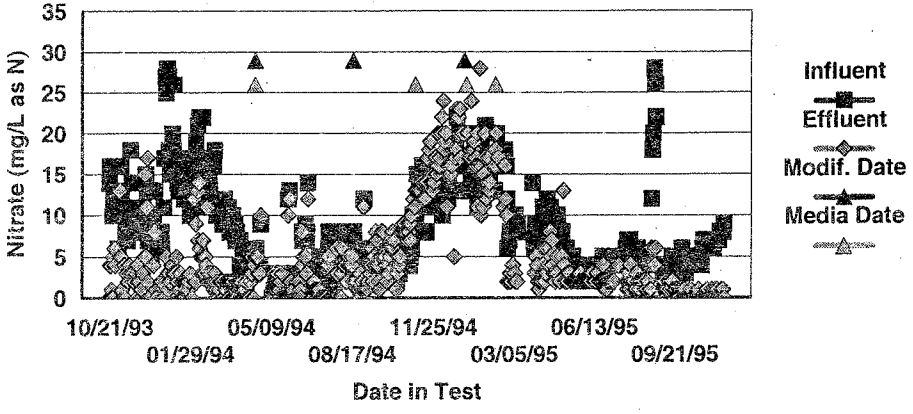


Figure 29
FBR1 - Influent and Effluent
Dissolved Oxygen

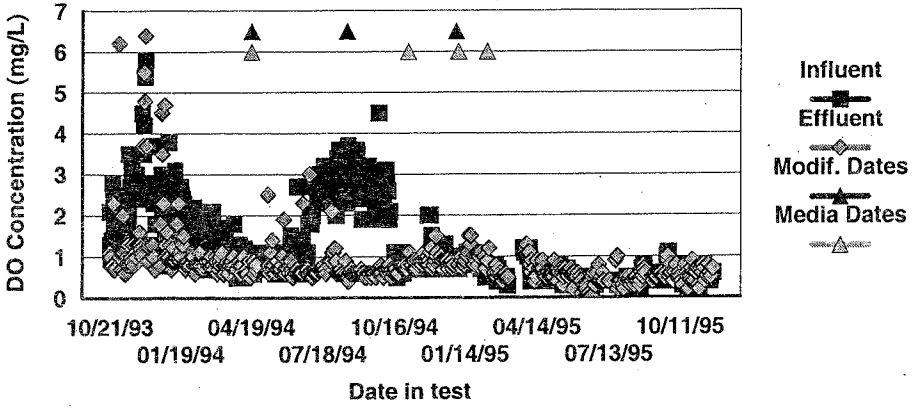


Figure 30
FBR1 - Reactor and Ambient Temperature

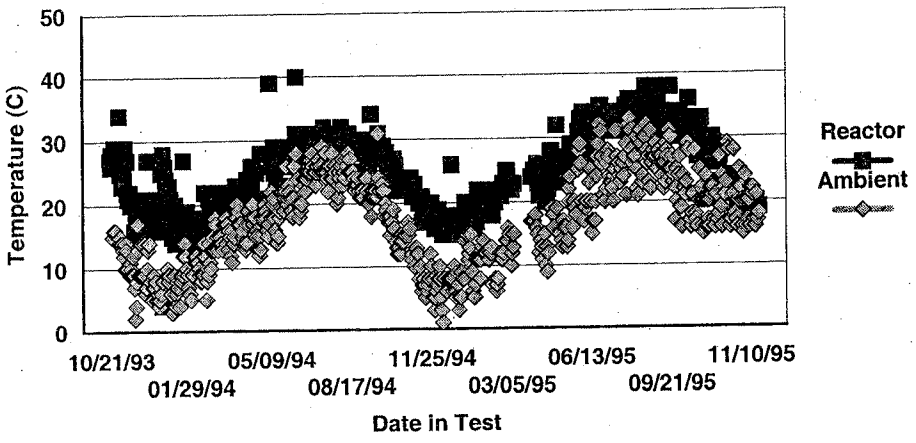


Figure 31
FBR1 - Influent and Effluent Alkalinity

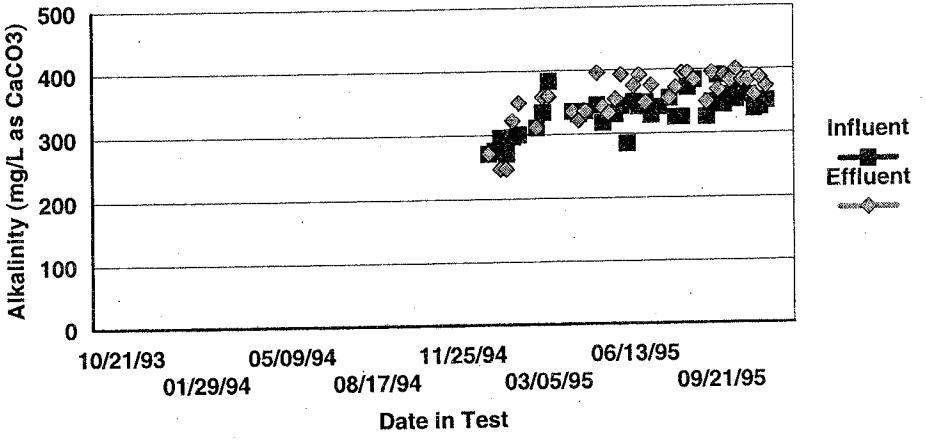


Figure 32
FBR1 - Influent and Effluent
Total Organic Carbon

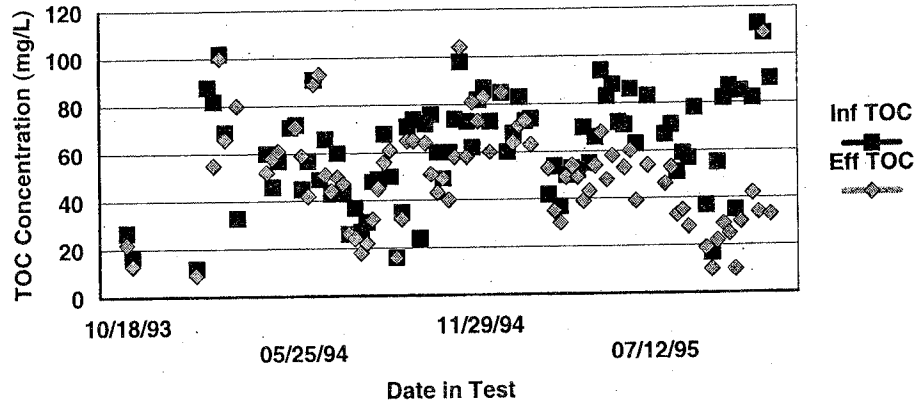
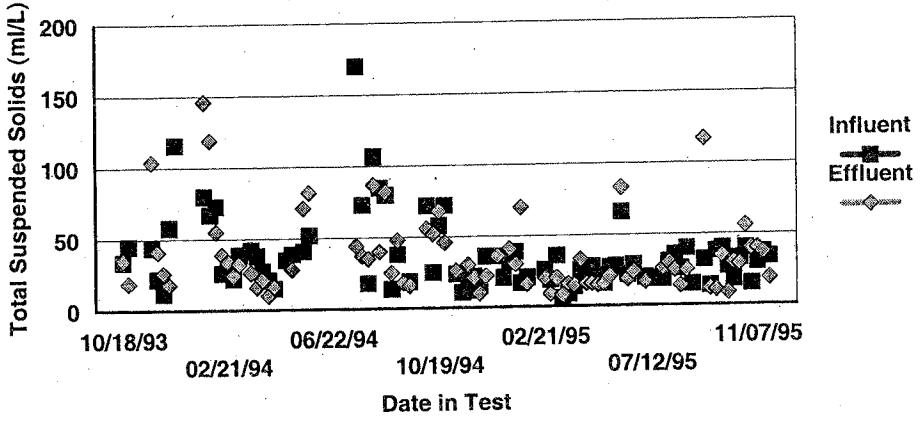


Figure 33
FBR1 - Influent and Effluent
Total Suspended Solids



TOC concentrations averaged 70 mg/L and 42 mg/L, while the influent and effluent TSS averaged 26 mg/L and 29 mg/L. Even though not shown in the figures, the influent and effluent volatile suspended solids concentrations remained fairly consistent and averaged 14 mg/L and 12 mg/L for the same period.

Fluidized Bed Reactor 2 Operations - October 13, 1993 through November 21, 1995

The period of testing with FBR2 corresponded with FBR1's time frame, which lasted 26 months from October 1993 through November 1995. FBR2 was operated as a first-stage treatment process to reduce both nitrate and selenium. FBR2 operations were continuous except for four periods of extended downtime for maintenance activities to make piping and reactor modifications and to solve operational problems. These four periods and reasons for the shutdowns were: December 17, 1993 (Day 459) through December 30, 1993 to replace recycle pump (seal failure) and to clean reactor; January 11, 1995 (Day 849) through February 2, 1995 to modify the reactor's distribution system; March 10, 1995 (Day 907) through March 30, 1995 due to flooding of the site; and April 7, 1995 (Day 935) through April 10, 1995 due to an electrical problem with the recycle pump.

The physical set-up for FBR2 was identical to that of FBR1, except that FBR2 was fitted a with chemical injection system to add methanol into the feedwater as a source of carbon required for denitrification.

Like FBR1, independent operation parameters tested for FBR2 were feed flowrate and depth of media. FBR2 was started at a feed flowrate of 1 gpm with a recycle flowrate that produced a 50 percent bed expansion. At 1 gpm, little or no denitrification occurred in the reactor, so on December 7, 1993, (Day 449), the inflow was reduced to 0.1 gpm. Inflow into FBR2 remained at 0.1gpm for the rest of the testing period. The upflow rate (influent rate added to recycle rate) for the entire testing period ranged between 7 and 55 gpm, with an average of 24 gpm.

Testing commenced with a media depth of 24 inches of #20 sand. Problems arose shortly after start-up. Effluent from the reactor was milky. On December 1, 1993 (Day 443), the reactor was shut-down for maintenance activities. The distribution plate, which was found to be 80 percent plugged, was changed and the support media was replaced with 25 inches of #12 sand (a finer sand). On December 7, operations resumed with an influent flowrate of 0.1 gpm. Operation notes from December 14 stated that the support media was being broken down and was carried out in the effluent. On December 17, the reactor was shut down due to a seal failure in the recycle pump. Again the distribution plate pores were found to be plugged with the support media fines. Scouring inside the column was also observed. The reactor was cleaned and put back into operation on December 30 (Day 472) with 12 inches of # 20 sand and at a feed flow rate of 0.1 gpm. The depth of media was changed three more times during the course of testing: reduced to 6 inches of #20 sand on November 11, 1994 (Day 788); increased to 12 inches on January 6, 1995 (Day 844); and again increased to 24 inches on February 24, 1995 (Day 893).

Like those for FBR1, operations for FBR2 were labor intensive. Problems arose due to biological growth and chemical precipitation in the piping, reactor, and recycle tank. As a result, the system required periodic cleaning that was usually performed when the system was modified or when the support media or media depth were changed.

The numerous modifications made to the influent manifold to improve flow distribution through the reactor were attributable to bacteria growth. Growth in the reactor was reduced and low dissolved oxygen levels were maintained in the reactor after placement of an insulator blanket around the reactor in February 1994. Distribution of flow into the reactor was improved when the distribution plate was replaced with a #6 mesh stainless steel screen in June 1994.

The methanol dosage system was a high maintenance item from the onset of operations. Numerous modifications were made to the methanol injection system during the first two months of operation to prevent blockage of the dosage line at the control metering valve. Placement of a back-pressure valve on the discharge line of the dosing pump in January 1994 helped alleviate some problems, but the dosing system still remained problematic. The targeted dosage rate was 300 mg/L from January 10, 1994 (Day 483) through July 25, 1994 (Day 679) when it was lowered to 240 mg/L. On August 1, 1994 (Day 686) the target rate was increased to 270 mg/L and remained the target rate for the remainder testing. The calculated dosage rates for these four periods in sequential order were 300 mg/L, 282 mg/L, 250 mg/L, and 274 mg/L.

Another problem area in operations was the maintenance of a realistic operating temperature inside the reactor. FBR2's temperature ranged between 17 and 42^0C, with an average of 30^0C. The reactor's temperature was influenced by the size of the recycle pump. The 2-horsepower recycle pump was changed to a 3/4-HP one on June 14, 1994, to lower the reactor operating temperature. On September 13, 1994, the 3/4-HP recycle pump was replaced with a 2-HP pump to improve bed expansion. The recycle pump was changed back to a 3/4-HP one on June 26, 1995, and was used for the remainder of the testing.

Fluidized Bed Reactor 2 Results

FBR2 was operated as a single-stage reactor to reduce both selenium and nitrate and was run in parallel with the UASBR. The influent selenium concentrations were those of the UASBR and were previously presented previously in the UASBR Period 3 section, Figure 13. The average influent Tse, Sse and selenite concentrations for the entire FBR2 operation period were 522 ug/L, 507 ug/L, and 3 ug/L, respectively. The effluent selenium values for the entire operation period are shown in Figure 34 and averaged 383 ug/L, 275 ug/L, and 36 ug/L for Tse, Sse, and selenite, respectively.

Figure 35 shows percentage of Sse reduced and dates on which the depth of the media and phosphate dosage were changed. Overall for the entire period, Sse reduction averaged 35%. The best reduction for an extended period was 68% that occurred between January 31, 1994 (Day 504) and September 14, 1994 (Day 730) at a media depth of 12 inches. Sse reduction averaged 50% from restart of the reactor on March 31, 1995 (Day 928) after flooding of the site until the end of operations on November 21, 1995 (Day 1163). Phosphate was dosed into the plant's influent at three rates during the course of testing. Phosphate was added to the influent to ensure adequate nutrients for biological growth. Initially, phosphate dosage was 0.5mg/L as P until August 1, 1994 (Day 710) when it was lowered to 0.25 mg/L as P. Then, on August 2, 1995 (Day 1052), the phosphate dosage was raised to 1.3 mg/L as P for the remainder of operations. Sse reduction for these three periods were 50.2%, 39%, and 55.3%. Sse reduction of 68.9% was

Figure 34
FBR2 - Effluent Total Selenium, Soluble Selenium and Selenite

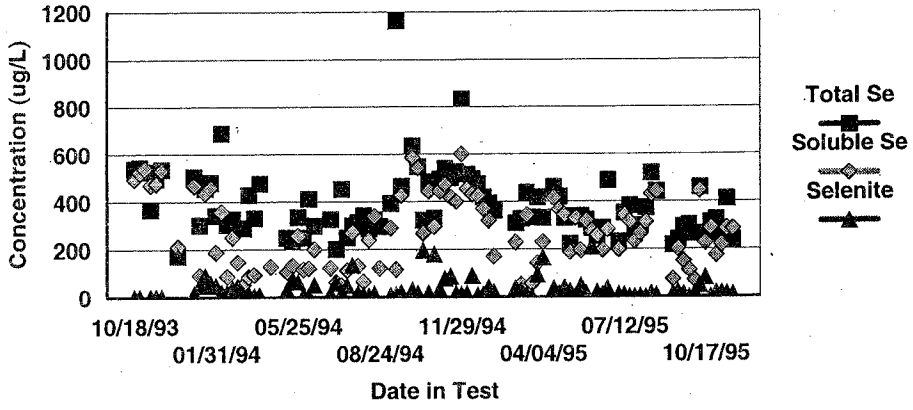


Figure 35
FBR2 - Percentage of Soluble Selenium Reduced and Dates for Media & Phosphate Dosage Changes

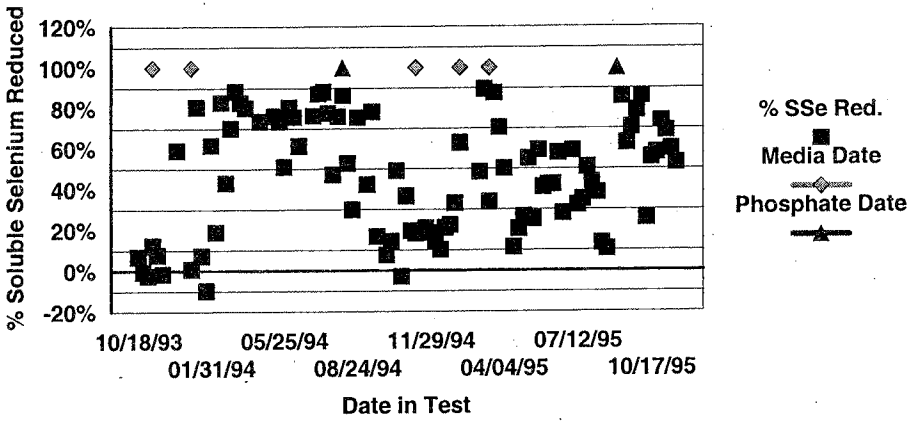


Figure 36
FBR2 - Influent and Effluent Nitrate

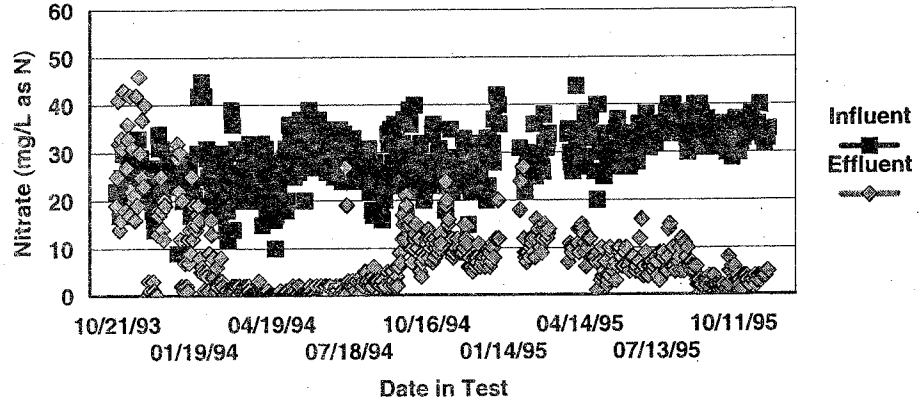
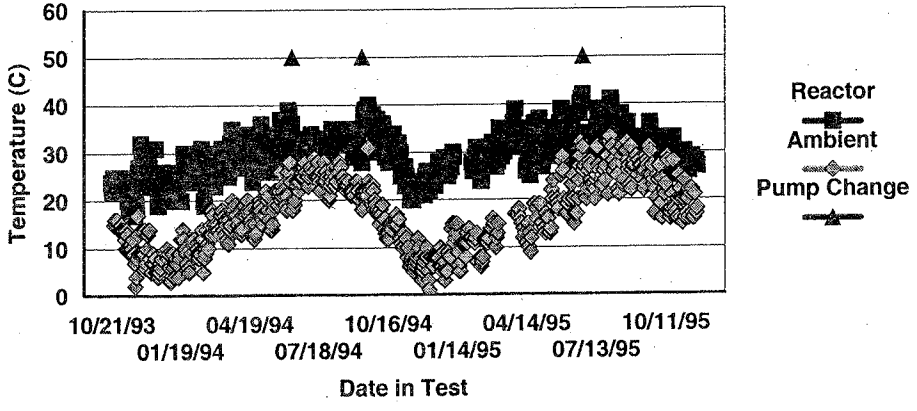


Figure 37
Reactor and Ambient Temperatures and Date for Recycle Pump Change



achieved from January 31, 1994 through August 1, 1994 when the phosphate dosage was 0.5 mg/L as P and media depth was 12 inches.

Influent and effluent nitrate concentrations for the entire operation period are shown in Figure 36 and averaged 29 mg/L as $CaCO_3$ and 7 mg/L as $CaCO_3$, respectively. From January 31, 1994 through September 14, 1994 when Sse reduction was best, the average nitrate effluent concentration was 2 mg/L as $CaCO_3$, while the effluent nitrate averaged 8 mg/L as $CaCO_3$ for the remainder of operations from September 15, 1994 to November 21, 1995.

Figure 37 shows reactor and ambient temperatures along with the identification of dates when the recycle pump was changed. The average temperature difference between the reactor and ambient temperatures were 14 °C and 16 °C for two periods when a 2-HP pump was used from October 21, 1993 through June 13, 1994 and September 12, 1994 through June 25, 1995, while the average temperature difference ranged between 7 °C and 8 °C for the two periods with a 3/4-HP pump.

Influent and effluent dissolved oxygen concentrations are shown by Figure 38. The influent DO concentration averaged 8.8 mg/L for the entire test period. Until February 11, 1994 (Day 515), the effluent DO concentration fluctuated and averaged 2.4 mg/L. After February 11, the effluent DO concentration stabilized and averaged 0.7 mg/L for the remainder of operations. Figure 39 shows methanol dosage into the influent stream of FBR2. As previously stated, there were four targeted rates during the course of testing. The operation of the injection system was problematic and tended to improve as modifications were made as testing progressed. The standard deviation four the four dosage periods in sequential order were 158 mg/L, 65 mg/L, 26 mg/L, and lastly 40 mg/L for the last 16 months of operation.

The influent and effluent total organic carbon concentrations are shown by Figure 40. Effluent was almost always in excess of the influent. Influent TOC averaged 47.7 mg/L, while the effluent averaged 12.8 mg/L for the entire test period. The effluent TOC concentration averaged 23.9 mg/L from January 31, 1994 through August 1, 1994, when the percentage of Sse reduction was the best at 68.9%. For this period the calculated methanol phosphate dosages were 282 mg/L and 0.5 mg/L as P, respectively, and the depth of media was 12 inches.

Figures 41 and 42 show influent and effluent volatile and total suspended solids concentrations, respectively. The effluent VSS concentration remained relatively constant for the last 18 months of operation, while the effluent TSS concentration varied considerably throughout the program. Overall for the test period, the influent and effluent VSS values averaged 5 mg/L and 22 mg/L and the influent and effluent TSS concentrations averaged 18 g/L and 52 mg/L, respectively.

Influent and effluent alkalinities are shown by Figure 43. On the average, alkalinity increased 59% through the reactor. For the entire testing period, the influent and effluent alkalinity averaged 186 mg/L as $CaCO_3$ and 295 mg/L as $CaCO_3$, respectively.

Influent and effluent electrical conductivities and total dissolved solids concentrations are shown in Figures 44 and 45, respectively. Surprisingly, the effluent EC was continuously greater than the influent. From March 8, 1994 through to the end of testing, influent and effluent EC values averaged 8,658 uS/cm and 9,956 uS/cm, respectively. The device to measure EC was replaced

Figure 38
FBR2 - Influent and Effluent
Dissolved Oxygen

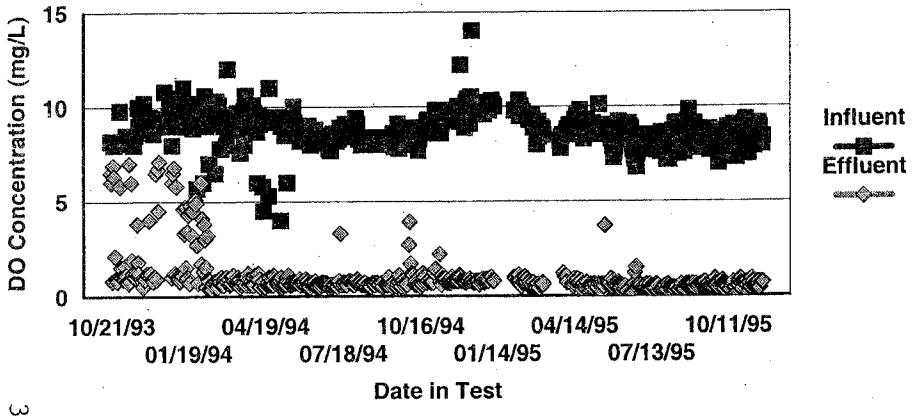


Figure 39
FBR2
Methanol Dosage

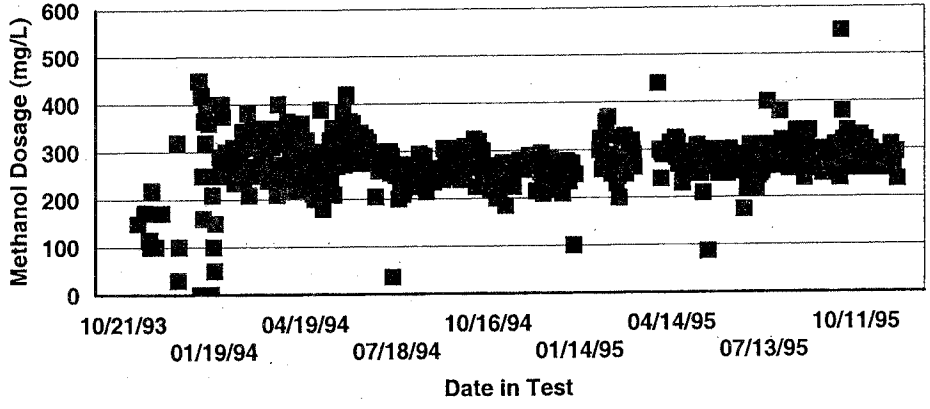


Figure 40
FBR2 - Influent and Effluent
Total Organic Carbon

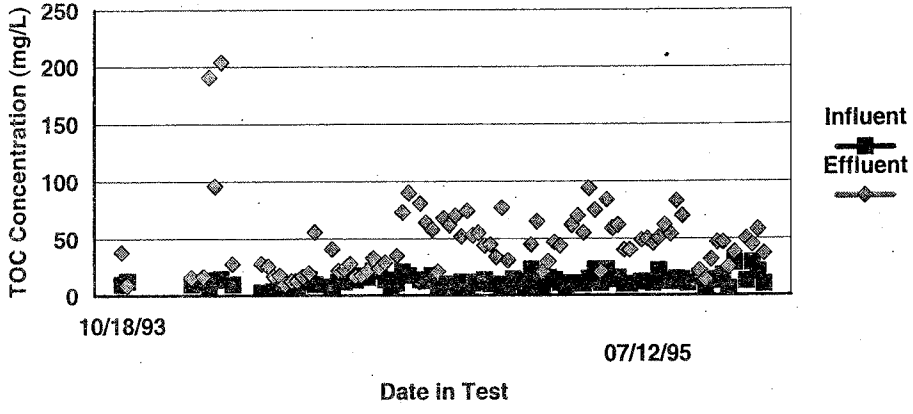


Figure 41
FRB2 - Influent and Effluent
Volatile Suspended Solids

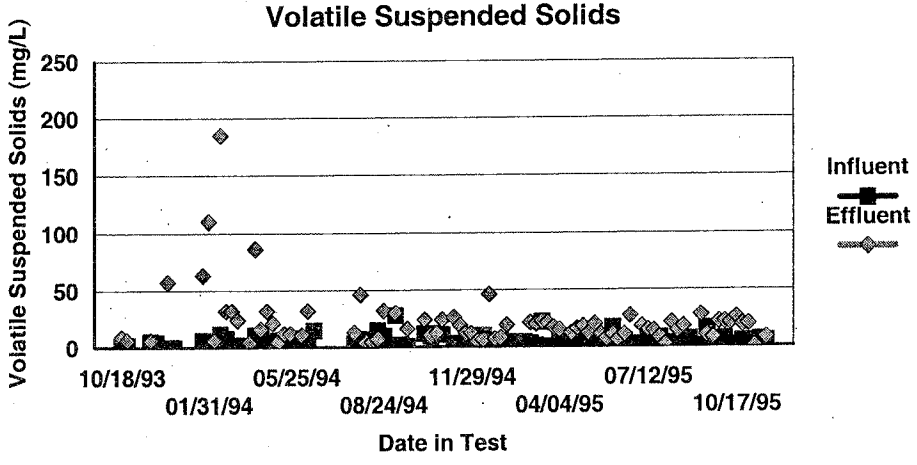


Figure 42
FBR2 - Influent and Effluent
Total Suspended Solids

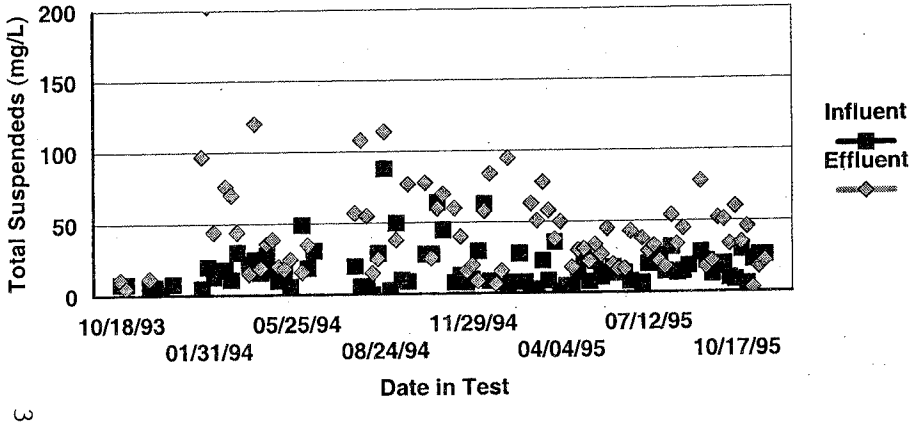


Figure 43
FBR2
Influent and Effluent Alkalinity

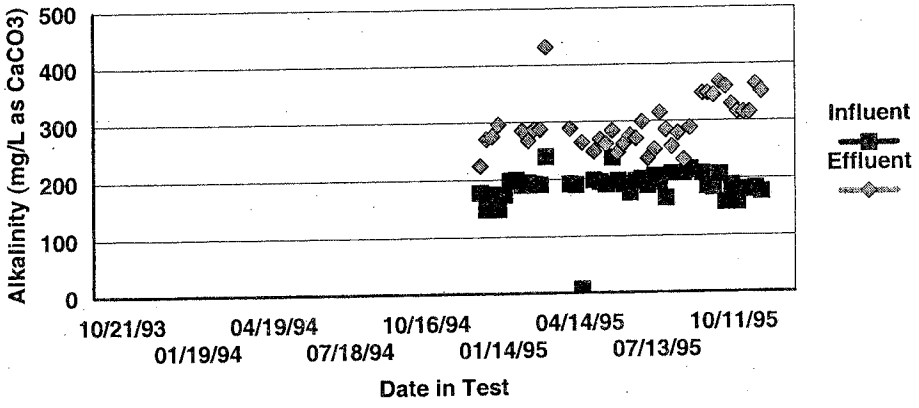


Figure 44
FBR2 - Influent and Effluent
Electrical Conductivity

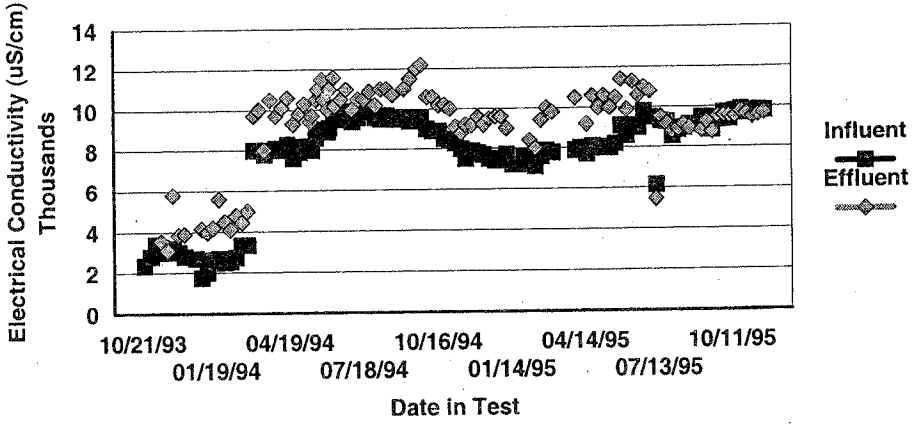
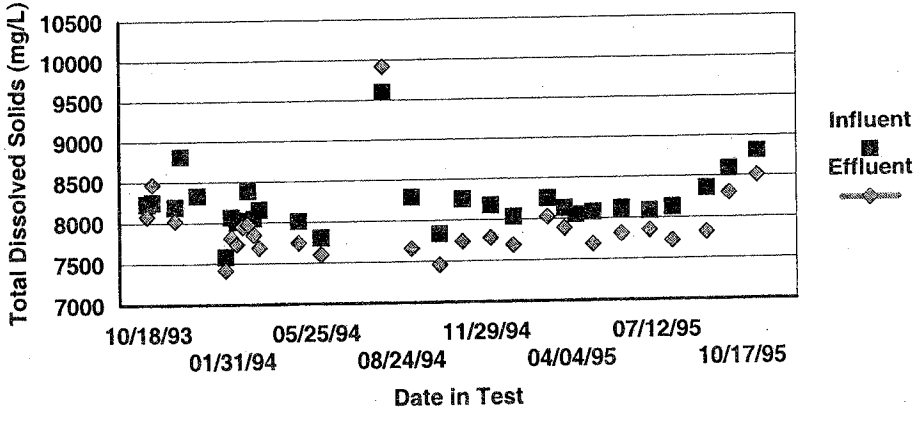


Figure 45
FBR2 - Influent and Effluent
Total Dissolved Solids



on March 1, 1994 because the EC measurements did not correlate to the laboratory TDS values. The influent and effluent TDS concentrations averaged 8,258 mg/L and 7,116 mg/L, respectively.